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Past tense –ed omissions by children with Specific Language Impairment; the role of sonority  
and phonotactics

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## Abstract

Children with Specific Language Impairment (SLI) frequently omit past tense –ed. Omission rates are subject to phonological context. Two phonological characteristics were manipulated; the sonority profile of the stem-final phoneme plus affix, and the phonotactic probability of the word-final phonemes (/i:pt/ in *beeped*). 17 children with SLI (mean age 6;7) and 21 language-matched children (mean age 4;8) repeated sentences containing regularly inflected verbs according to a 2 (sonority) by 2 (phonotactic legality) design. Affix omissions were analysed. There was a significant effect of sonority only, characterised by a difficulty with level-sonority clusters, and no interaction. Syllabic affixes, e.g. *head-ed*, were produced relatively accurately. It is argued that –ed omissions in SLI may reflect a low-level speech or articulation difficulty which surfaces in uniquely challenging clusters. This is not an alternative to morphosyntactic accounts; rather past tense omissions are best explained according to complexity in multiple domains; syntactic, morpho-syntactic and phonological.

## Literature Review

*Tense in SLI*

Children with Specific Language Impairment (SLI) have language difficulties with no obvious causal mechanism, e.g. learning difficulties, hearing impairment, and known syndromes such as autism. Prevalence is estimated to be about 7% (Tomblin, Records, Buckwalter, & Zhang, 1997). While difficulties are evident across a range of language subdomains, including phonology, pragmatics, and vocabulary, it is often argued that morphosyntax is most severely affected (Leonard, 2000). Within morphosyntax, there has been a strong research focus on verb affixation, in particular marking of finiteness. In English, children with SLI are particularly likely to omit the past tense affix (/t/ /d/ or /Id/), and this may constitute a reliable psycholinguistic marker (Conti-Ramsden, Botting, & Faragher, 2001).

There have been numerous accounts of past tense difficulties in SLI, some of which emphasise the phonological characteristics of past tense forms (e.g. Marshall & van der Lely, 2006), while others focus on past tense as a syntactic phenomenon (e.g. Rice & Wexler, 1996). While it is likely that both phonology and syntax play a role in past tense difficulties, this study focuses on the former, in particular the role of phonotactics and sonority. The literature review surveys a range of different accounts, and argues that sonority is a potential explanatory factor whose impact has until recently been relatively underinvestigated.

*Factors affecting tense*

Studies investigating the role of phonology on past tense formation in SLI have focused mainly on phonotactics and the existence of clusters. Marshall and van der Lely (2006) investigated the effect of stem-plus-affix phonotactics on past tense inflection by

children with Grammatical-SLI (G-SLI; mean age 11;03), who perform particularly poorly on syntactic assessments e.g. comprehension of passive sentences. They identified difficulties on verbs ending in phonotactically-illegal strings, where the term “phonotactics” refers to segmental patterns within morphemes. For example, verbs ending VC/t/ or VC/d/, e.g. *packed*, tend to be phonotactically legal, rhyming with the monomorphemic words *pact*, *act*, and *fact*. However, words ending VVC/t/ or VVC/d/, e.g. *beeped*, tend to be phonotactically illegal as they do not rhyme with a monomorphemic equivalent. The study observed a Group by Legality interaction such that the children with SLI were much more likely than language-matched controls to omit past tense /t/ and /d/ when it resulted in a phonotactically illegal stem + affix combination. A further study by Leonard, Davis and Deevy (2009) also found a greater effect of the phonotactic probability on affixation of nonword stems in children with SLI (mean age 5;4) than in age-matched and language-matched controls when participants were required to inflect nonwords. Here phonotactic probabilities were calculated across the experimental words, by summing the positional and biphone frequencies. Finally Marshall, Marinis and van der Lely (2007) found that children with G-SLI were less able to use phonotactic cues to correctly parse regular past participles as participles in order to interpret passive sentences. Here, illegal phonotactics provide a strong cue for inflection, which the children with G-SLI were less sensitive to.

A separate body of research has highlighted the importance of the stem-final phoneme to which children must add the inflection. A number of studies have found that stem-final consonants, which result in an inflected form ending in a consonant cluster, pose particular difficulties. Marshall and van der Lely (2007) identified particularly poor performance by 12-year-old children with Grammatical SLI on the elicitation of verbs ending in consonant clusters, as demonstrated by a Group (G-SLI versus language-matched) by Cluster interaction. Oetting and Horohov (1997) found that 6-year-old children with SLI

found forms ending in obstruent + /t/ or /d/, e.g. *grabbed*, *knocked*, significantly more difficult than forms ending in a liquid or glide + /t/ or /d/, e.g. *pulled*. This effect was much weaker in age and language-matched controls, resulting in a Group x Phonological Composition interaction. This finding differs slightly to that of Marshall and van der Lely (2007) in that nasals and liquids were excluded from the clusters under examination as these are not regarded as obstruents. In addition, two single case studies of children with SLI (Eyer & Leonard, 1994; Johnson & Morris, 2007) observed that verbs ending obstruent + /t/ or /d/ posed particular difficulties. Finally, Marchman Wulfeck and Ellis Weismer (1999) found that a stem-final alveolar stop /t/ or /d/ proved particularly difficult for children with SLI. Such verbs, e.g. *thudded*, *started*, are atypical in the sense that affixation requires the addition of a syllable /Id/ or /It/.

#### *Explanatory accounts*

A number of explanatory accounts have been proposed to explain these patterns. With regard to the role of phonotactics, Marshall and van der Lely (2006) argue that their findings support the Dual Route model (Pinker & Ullman, 2002; Ullman & Pierpont, 2005). The main premise of their argument is that phonotactic constraints emerge via the analysis of lexical / phonological information in declarative memory. We can explain the greater role of phonotactic probability in the SLI group if we assume that they are using declarative memory to store multi-morphemic words as unanalysed wholes. This contrasts with typically-developing children who are able to use the computational system to generate inflected forms via the application of a rule. In this account, the role of phonotactics is used as an indicator of a deeper difficulty affecting the computational system, and it does not necessarily imply that children with SLI are more or less sensitive to phonotactics. Leonard, Davis and Deevy (2009), by contrast, propose an explanation based on the finding that phonotactic probability is a key determinant of word-learning (Storkel, 2001). Children with SLI find it especially

difficult to learn verb stems with low phonotactic probabilities, and this in turn may impact on affixation. A recent study also observed a similar effect in German-speaking children with SLI (Ott & Hoehle, 2013)

A further account proposed by Marshall and van der Lely (2007) moves away from phonotactics to investigate the role of syllable structure. The authors argue that children with G-SLI have difficulties producing branching constituents, e.g. branching onsets, nuclei or codas, which may reflect limited phonological computation mechanisms. They observe that there is a parallel between this kind of structural simplification and corresponding difficulties understanding and producing complex syntactic structures, and both processes may share a common underlying mechanism. A further study on Russian-speaking children with SLI repeating non-words corroborates the finding of severe difficulties with clusters (Kavitskaya, Babyonyshev, Walls, & Grigorenko, 2011).

Perceptual difficulties may also play a role. An auditory perceptual deficit was first identified by Tallal (1975), who found that children with SLI were poor at detecting pitch changes when sound stimuli were closely spaced and hence involve rapid temporal changes. Such a difficulty might also impact on the perception of affixes, e.g. –ed, and plural –s, which involve rapid changes in spectral characteristics. More recently, Leonard and Eyer (1996) have proposed that a perceptual deficit combined with a processing capacity limitation can account for morphosyntactic difficulties in SLI, a theory known as the Surface Account. However, the role of perceptual difficulties has been questioned as children with SLI do not require more phonetic information than controls to identify an inflected form (Marshall & van der Lely, 2008)

An account of past tense production which has implications for SLI, but has not, to the author's knowledge, been applied to language difficulties, is Bybee and Slobin's schema

theory (1982). They argue that regular past tense production is initially governed by a “product-oriented” schema whereby children represent the regular past tense in terms of the product or output of a morphophonological process. According to their data, children assume that past tense forms end with an alveolar plosive. In other words, they operate with the past tense schema PAST TENSE VERB = \_\_[+alveolar, +plosive], i.e. a word ending in an alveolar plosive. Consequently, those verb stems which already end in an alveolar plosive are less likely to be inflected. These claims have been supported by a recent large-scale study finding evidence for product-oriented schemas in young children (Matthews & Theakston, 2006). Eventually, in typically-developing children, the product-oriented schema becomes less entrenched, and the default suffixation rule takes over. However, it is possible that children with SLI maintain the product-oriented schema for longer. This may be a consequence of taking longer to build up a “critical mass” of exemplars in order to extract the rule (Jones & Conti-Ramsden, 1997). Such an account is corroborated by Marchman et al.’s (1999) finding of greater omissions of affixes for verbs ending in alveolar plosives. However, though this would only explain greater difficulties with verbs ending in alveolar stops, e.g. *spot* → *spotted*, it does not account for difficulties with clusters which do not trigger the addition of a syllable, e.g. *dropped*, *cracked*. One possibility is that children are operating with a product-oriented schema containing relatively abstract categories; PAST TENSE VERB = \_\_[+consonant] or \_\_[+plosive].

It should be reiterated that syntactic accounts of –ed omission have been proposed. One account of past tense difficulties which does not address the role of phonology is the Extended Optional Infinitive (EOI) Account of Rice and Wexler. This proposes that children with SLI undergo an extended period where they are unaware that tense is an obligatory feature of well-formed sentences. This may be linked to an innate maturational mechanism. In support of this claim, children with SLI are poor at detecting past tense inflection errors in



grammaticality judgement tasks (Rice, Wexler, & Redmond, 1999). This indicates that difficulties go beyond output phonology, and may therefore reflect grammatical competence. Another account of past tense production which does not directly address the role of phonology is based on the MOSAIC model (Freudenthal, Pine, Aguado Orea, & Gobet, 2007). According to this model, zero-affixation can be explained by a focus on utterance-final words which tend to be uninflected, .e.g. *where would you like to go?* Though this model has not been specifically applied to SLI there is independent evidence that these children may be excessively focused on utterance-final words (Leonard & Deevy, 2011). Like the EOI, MOSAIC does not rule out the possibility that specific phonological processes may also be at work.

### *The role of sonority*

A relatively underinvestigated factor is sonority. This refers to the relative openness of the vocal tract and constriction of air flow. Consonants are less sonorant than vowels as they restrict the air flow, and in the case of plosives and affricates, temporarily stop the air flow altogether. Numerous sonority hierarchies have been devised. A widely used scheme is that of Burquest and Payne (1998) ; [a] > [e o] > [i u] > [r] > [l] > [m n] > [z v ð] > [s f θ] > [b d g] > [p t k], which follows the categories [low vowels] > [mid vowels] > [high vowels / glides] > [approximants] > [laterals] > [voiced fricatives] > [voiceless fricatives] > [voiced plosives] > [voiceless plosives]. Affricates are missing from the above hierarchy, but tend to be placed above plosives. Across languages syllables tend to display an upside down U-shaped sonority profile, characterised by low sonority the beginning of the syllable, high sonority in the middle of the syllable, and possibly, though not always, a lowering of sonority towards the end, a pattern often referred to as the Sonority Sequencing Principle (SSP: Clements, 1990). Consonant clusters in onset and coda position, likewise tend to follow the

SSP. For example, /f/ comes before /l/ at the onset of a syllable demonstrating rising sonority, e.g. *flow*, but after /l/ at the end of a syllable (coda) demonstrating falling sonority, e.g. *elf*.

The data on past tense production in SLI (Table 1) suggest that sonority may be an important principle, with affixes more prone to omission after consonants versus vowels, obstruents versus sonorants, and plosives versus continuants. Unfortunately, as different studies have carved up the sonority continuum in different ways, and also as the role of stem-final plosives is confounded by the syllabic nature of the ensuing affix, the data on the role of sonority is so far only suggestive. In addition, few studies have focused on distinctions at the lower end of the sonority gradient. However, a meta-analysis (Table 1) finds that across a range of studies, items ending in a high-sonority segment are easier to inflect than those ending in a low-sonority segment, though it should be noted that none of the authors explicitly mention sonority itself as a factor. It could thus be the case that sonority acts as a unifying explanation for the types of stem-final phonemes which are likely to trigger affix omission.

### *The focus of the study*

This study investigates the impact of sonority and phonotactics on past tense production in SLI. These, broadly, represent the two main accounts of how past tense –ed omission in SLI is influenced by the identity of the preceding phoneme or phonemes. The sonority profile is operationalised as level, e.g. *dropped*, or falling, e.g. *played* and phonotactic probability was calculated on the basis of the V(V)Ct cluster. The main aim was to determine which factor was the main determinant of –ed omissions.

## Methodology

### *Participants*

17 children with SLI aged 6;0 to 7;2 (mean 6;7) were recruited from language units attached to mainstream schools in the South East of England. Recruitment letters were

sent to Speech and Language Therapists, requesting that children meet criteria for SLI, with structural language difficulties, and no non-verbal learning difficulties, hearing difficulties, autism spectrum disorders, or other known syndrome. No child had been diagnosed with a disorder interfering with intelligibility, e.g. dyspraxia or oromotor difficulties, according to a screening questionnaire. The recruitment letters specified that children should speak English as their main language. In the questionnaire the therapists were invited to provide additional relevant information and none identified successive bilingualism as a causal factor. An open question also asked therapists Nonverbal abilities were assessed using the Wechsler Preschool and Primary Scale of Intelligence core subtests (WPPSI-3: Wechsler, 2002) with all children obtaining standard scores greater than 85. A variety of language assessments were used for screening; Word Structure (WS) from the CELF (Wiig, Secord, & Semel, 1992) the Renfrew Action Picture Task (RAPT: Renfrew, 1997), the Test of Reception of Grammar-Electronic (TROG-E: Bishop, 2005), and the British Picture Vocabulary Scales (BPVS: Dunn, Whetton, & Burley, 1997). WS and RAPT assess expressive syntax, with both tests designed to elicit specific syntactic structures at both morpheme and sentence level. The TROG-E was chosen to assess receptive syntax. This version of the CELF was chosen as it is standardized across a wide age range, allowing the same assessment to be used with all children. Children were diagnosed with SLI if they fell below -1 standard deviations on 2 or more of these assessments.

17 Language-matched (LM) children aged 4;4 to 4;9 (mean 4;8) were recruited from mainstream schools and nurseries via head teachers, with language matching accomplished via MLU-in-words (MLUw). Identical instruments were used, with every child scoring > 80 on the WPPSI, and no child scoring < -1 standard deviations on more than one language assessment. Narratives were elicited from the children in order to calculate their MLU-in-words (MLUw) for group-matching purposes. The two narratives were the *Bus Story*

(Renfrew, 1991) and *Frog, Where Are You* (Mayer, 1969), often referred to as the *Frog Story*. While the Bus Story involves the experimenter telling the story first, the Frog Story involves the child building their own narrative from pictures. The children's speech was transcribed using conventions proposed by Miller (1981). Samples contained mean 67.0 utterances (s.d. 22.1) in the SLI group, and mean 55.1 (s.d. 16.1) in the LM group. Table 2 shows psychometrics and significant group differences.

All children were able to produce word-final alveolar plosives with relatively high accuracy in monomorphemic contexts. This was determined using audio-recordings of the children's narratives and repetitions of the filler stimuli (see Procedure for details of narrative and repetition tasks and reliability measures). Words were selected if they were monomorphemic, ended in a word-final alveolar plosive and were followed by a vowel, /h/, or a sentence boundary. Words followed by a consonant except /h/ were excluded as it was difficult to perceive the alveolar plosive in these contexts. In addition, the conjunction *and* was not scored as it was prone to phonetic reduction (/ən/). The perceived use of a glottal stop was classed as correct, as this may result from a failure to release the target consonant, but any other deviations, e.g. /t/ → /k/ or /g/ were classified as incorrect. On average there were 38.7 codable words per participant (s.d. 12.2, min 15, max 71).

### *Stimuli*

The past tense stimuli (Appendix) were created according to a 2 (phonotactic probability) x 2 (sonority profile) design. Following Marshall and van der Lely (2006) phonotactic probability was determined by investigating whether the combination of the stem final vowel (both short and long), stem-final consonant (if there is one), and past tense affix occurred in monomorphemic English words. For example, /ækt/ in the verb *packed*, also occurs in numerous monomorphemic words, e.g. *fact*, *act*, *pact*, *tact*. Likewise /eid/ in *played*, occurs in *lemonade*, *parade*, *marinade*, and *cavalcade*. However, there are no

monomorphemic words ending in /i:pt / or /ʊkt/. In order for a word to be deemed phonotactically legal it needed to have at least five monomorphemic equivalents in the CELEX database (Burnage, 1990). The phonotactically illegal words did not have a monomorphemic equivalent.

It should be noted that the term “phonotactics” is a general term used to describe constraints on the co-occurrence of phonemes. Phonotactic probabilities will vary according to where adjacent phonemes occur within syllable structure, and whether they span a morphological boundary. There are thus numerous ways to calculate phonotactic probabilities, e.g. at the whole word level (including affixes), at the word root level, or within syllables. The definition of phonotactic legality used by the current study is calculated on patterns occurring within word roots, and the patterns identified as “illegal” are therefore attested across morpheme boundaries. However, their transitional probabilities are clearly much lower than patterns occurring within roots. There is an important theoretical motivation for defining legality in this manner. Marshall and van der Lely (2006) argued that, in children with SLI, inflected forms are stored in declarative lexical memory, which according to a number of models (e.g. Pinker & Ullman, 2002), is dedicated to the storage of uninflected forms. If this is the case, then the inflected forms should be governed by the same phonotactic constraints as the uninflected forms, assuming that such constraints result from the statistical analysis of lexical material within declarative memory. From this perspective, it makes sense to calculate phonotactic probabilities within word roots.

It should also be noted that though following the principles of Marshall and van der Lely (2006), the procedure differed slightly in that it did not use abstract Consonant and Vowel Categories. For example, while Marshall and van der Lely regarded VCt verbs, e.g. *dropped*, as phonotactically legal, given that the vast majority of these verbs correspond to patterns in monomorphemic words (e.g. *opt*, *adopt*) the current procedure identified *booked*,

also a VCt structure, as being phonotactically illegal as the phoneme string /ukt/ does not occur in monomorphemic words.

In addition to stimuli with a segmental affix (/t/ or /d/) stimuli were also generated with a syllabic affix (/It/ /Id/), as in *headed*, *spotted*. These were deemed phonotactically legal as there are numerous monomorphemic words ending with the /tId/ and /dId/ sequence, e.g. *fetid*, *candid*. All verbs were transitive, as they were presented in transitive syntactic frames (see below). Given the phonological and syntactic constraints involved in selecting the stimuli it was difficult to exercise control over a variety of other potential factors including frequency and clusterhood (*played* and *poured* both lack consonant clusters, ending vowel-consonant, and are therefore different from the rest of the stimuli in the same cell of the design). In light of this, frequency, and clusterhood were tested as covariates.

Each verb was presented in two different frames; a two-place predicate and a three-place predicate, e.g. *the boy picked a flower* and *the boy picked a flower for his girlfriend*. Grela and Leonard (2000) found an effect of verb valency on the production of auxiliary verbs, possibly due to a capacity limitation, and this design allows us to determine whether similar factors affect the realisation of the regular past tense. There were 25 verbs and 2 frames per verb, making 50 sentences altogether.

### *Procedure*

The stimuli were presented in sentences, as part of a sentence repetition task (SR) which investigated repetition of complex structures such as relative clauses, questions and passives (Riches, 2012). The sentences were presented using a laptop computer via headphones (Sennheiser PC156Headset), and the child's responses were recorded straight to the computer via the mouthpiece which was positioned close to the child's mouth. The task was introduced with a warm up involving a cuddly parrot who "produced" the sentences via a

hidden conference point which sent a signal to the laptop computer. The experimenter pretended not to understand the sentences, and the child had to “interpret” by repeating them. This was found to be the best way to elicit the sentences during piloting. The sentences were presented via DMDX software in blocks of 20. As the child heard each sentence a number appeared in one of the blocks. This helped to motivate the child and inform them of how many sentences remained. After the final sentence, a reward screen appeared with a picture of people cheering and a clapping sound.

### *Scoring and reliability*

Responses were scored as inflected or uninflected by the author from the recorded audio files. Substitution of /t/ or /d/ by a glottal stop were accepted, as glottalisation is a common characteristic of local dialects, but other substitutions were not. Two independent raters checked a total of 19% of the repetition attempts, selected from 6 children with SLI and 4 LM children who were selected entirely at random. Disagreements arose for 2.3% of the interrater sentences (17 sentences altogether). For only one of these sentences disagreement concerned the verb itself, with the coder hearing *beep*, and the rater hearing *beat*. One of the raters also checked the narrative transcripts for two children with SLI, and one LM child, comprising 11% of the narrative data. There were no disagreements regarding the coding of word final alveolar plosives.

## Results

### *Data screening*

Occasionally the participants repeated the sentence without including the verb, and therefore the sentence was not codable for the purposes of analysing past tense production. Consequently, the data were checked to ensure that all of the participants produced a sufficient number of codable observations. Children in the LM group produced a mean of

48.7 codable observations out of a maximum of 50 (s.d. 1.4, min-max 45 – 50), while children in the SLI group produced a mean of 43.8 (s.d. 5.9, min-max 29 – 50). Overall, only 12% of the observations in the SLI group were uncodable.

While it is not ideal to have missing data, there are good reasons for assuming that this does not impact on the findings. Firstly, performance on individual items (dichotomously coded as 1 = affix produced, 0 = affix absent) was used as the dependent variable, not number of items correct. Consequently the dependent measure does not fluctuate according to the number of observations per cell. Secondly, experimental condition was entered as a fixed factor, which effectively controls for the number of observations per cell. Thirdly item number was also entered as a random factor thereby controlling for the possibility that certain items led to high rates of non-codable responses. Finally, there was no significant effect of experimental condition on numbers of codable responses according to a linear regression with legality sonority and the legality x sonority interaction as independent variables. This suggests that patterns of omission occurred at random.

#### *Analysis of overall past tense performance*

Rates of past tense affix omission were higher in the children with SLI than the LM children (mean 21.9%, s.d. 20.1% versus mean 0.4%, s.d. 1.4%). Histograms for each group are plotted in Figure 1. While omission rates overlapped, the children with SLI were characterised by a flatter distribution with a longer tail consisting of 5 children who made omissions at rates greater than 20%. Differences in past tense affix omission were highly significant ( $t(35) = -4.61, p < 0.001$ ). This confirms previous findings that past tense omission lags behind language-matched peers and can be characterized as a delay-within-a-delay. As rates of past tense omission were so low in the control children they were not included in the analysis of profiles (below)



To ascertain the role of speech difficulties specific to alveolar plosives, omissions of word-final /t/ and /d/ in monomorphemic contexts were compared. Omission rates were higher in the children with SLI (mean 9.9%, s.d. 6.2% versus mean 4.1%, s.d. 4.3%), and differences were statistically significant ( $t(35) = -3.30$ ,  $p = 0.002^{**}$ ). This suggests that difficulties with the realization of the past tense affix by children with SLI could reflect a general difficulty with /t/ and /d/ morphemes in word-final context.

To further investigate this possibility, an Ordinary Least Squares (OLS) regression was conducted with rates of past tense affix omission as the dependent variable, and both Group (indicator coded) and omission rates for word-final /t/ and /d/ in monomorphemic contexts as the independent variables. While there was a significant effect of omission rates for /t/ and /d/ in monomorphemic contexts ( $\beta = 1.21$ ,  $t = 2.40$ ,  $p = 0.022^{*}$ ) the Group factor was also significant ( $\beta = 0.15$ ,  $t = 3.15$ ,  $p = 0.003^{**}$ ). Consequently, differences in rates of past tense affix omission across the groups were not wholly explainable in terms of a generalised difficulty with word final alveolar plosives.

### *Analysis of profiles*

Before investigating the effect of condition (phonotactic legality and sonority profile) a series of one-way analyses was conducted to investigate variables which could be included in the analysis of condition as covariates. It was decided to test these individually and include them if they significantly predicted performance, as inclusion of all possible covariates at once might lead to an overfitted model. Logistic regressions, which are designed to model dichotomous data, were employed, and potential covariates were used as predictors. The dependent variable was coded 1 if the affix was produced and 0 if the affix was omitted. Standard errors were clustered by participant using the “cluster” option in STATA. The first potential covariate was the percentage of /t/ and /d/ endings omitted in monomorphemic contexts; a by-participant measure. Then a series of by-item covariates were investigated; the

valency of the argument structure (two- versus three-place predicates), clusterhood (whether the inflected form ended in a CC cluster), lemma frequency (e.g. frequencies of *use*, *used*, *using*, *uses* combined), and frequency of the inflected form (e.g. *used* only). This makes 5 regressions altogether. Clusterhood was deemed important as some of the legal falling sonority items contained the /st/ cluster, which could act as a potential confound. The frequencies of lemmas and inflected forms was derived from a search of the British National Corpus via an online portal. Only the first variable (omission of /t/ and /d/ endings) significantly predicted performance ( $\beta = 1.49$ , Odds Ratio = 4.44,  $z = 2.61$ ,  $p = 0.009^{**}$ ) and was therefore included in the final regression model.

The effects of treatment condition (phonotactic legality and sonority profile) were subsequently investigated. To recap, this analysis is for the SLI group only, as the LM group did not make sufficient errors to warrant analysis. Summary data are shown in Figure 2. While both legality and sonority profile impacted on rates of suffix omission, the effect of sonority profile was larger (Cohen's  $d = 0.33$  versus  $0.15$ , legal syllabic items excluded). The syllabicity of the affix had relatively little impact on omission rates. In fact, syllabic /Id/ was marginally less likely to be omitted than segmental /t/ or /d/.

Finally, an analysis of condition was conducted using a mixed effects logistic regression. Predictors were sonority, legality and the interaction term, and the dependent variable was coded 1 if a verb included the affix and 0 if the affix was omitted. Importantly, syllabic affixes were dropped from this analysis, as syllabicity may be a confounding factor. Percentage of omissions in monomorphemic contexts was included as a covariate, being the only potential covariate which significantly predicted performance in the one-way analyses.

Mixed effects models are powerful because they can simultaneously model by-participant and by-item random effects (see Baayen, Davidson, & Bates, 2008 for a

discussion). An additional benefit of this type of model is that it deals well with missing values. Initially a maximal model was fitted containing within-subjects fixed effects (legality and sonority), by-subject slopes for fixed effects interaction terms (if any), and item number as a fully-crossed random effect (Baayen et al., 2008). The role of item was tested using likelihood ratio tests, to see if it contributed significantly to the model, in which case it was retained. All other random effects were kept as they contained slopes for variables of interest (Barr, Levy, Scheepers, & Tily, 2013).

The regression results are shown in Table 3. There was a significant effect of sonority profile, no significant effect of legality and no sonority by legality interaction.

### Discussion

The children with SLI made far more past tense affix omission errors than language-matched typically-developing children, consistent with previous findings in the literature. While there was some evidence that the phonotactics of the stem + affix combination played a role in omissions within the SLI group, the sonority profile of the final two phonemes (level versus falling) was a stronger factor. There was no evidence of an interaction between these two factors.

The data call into question a number of accounts of regular past tense difficulties in SLI. Verb valency (2 versus 3 argument structures) had relatively little impact on rates of morpheme omissions. This contrasts with the findings of Grela and Leonard (2000) who, in an elicitation study, observed an effect of valency on the realisation of auxiliary verbs, an effect they attribute to the greater processing load incurred by the extra arguments. Differences in findings may be attributable to the different paradigms (sentence repetition versus elicitation) and focus on different grammatical morphemes (auxiliary verbs versus past tense inflection). There was likewise little evidence that the children were operating with an

immature product-oriented \_t/d schema of the kind which characterises younger children (Bybee & Slobin, 1982). This would have resulted in particularly high omission rates for syllabic –ed, as the stem already ends in alveolar plosive. Nonetheless it is possible that actually presenting the inflected form in a sentential context, the syllabic nature of the affix was made highly salient, and children may not have performed so well on syllabic affixes in an elicitation task. An elicitation paradigm may have been better suited to testing this hypothesis.

The role of phonotactics of the stem + affix combination (Marshall & van der Lely, 2007) was not strongly supported, with greater omissions for phonotactically illegal word endings, though results fell short of significance. However, it should be noted that the children with SLI were not defined according to the narrow syntactic criteria employed by Marshall and van der Lely, hence the groups may not be directly comparable. It is also possible that with increased power this effect may have become significant. What the results do suggest is that regular inflection by children with SLI as opposed to G-SLI does not appear to be greatly informed by phonotactic frequency. It should be noted that the study did not investigate how the phonotactics of the stem itself (Leonard et al., 2009) influenced production.

The findings are partially consistent with the role of phonological complexity as the condition containing only 50% consonant clusters (legal strings with falling sonority) exhibited the lowest error rates. However, the study suggests that error rates are influenced not just by phonological structure, operationalised using vowel and consonant categories, but also by sonority distinctions within the consonant category. Consequently, phonological schemas such as .CVVC .CVC and .CVCC may be too broad to capture the omission phenomena.

The main finding of the study was the important role of sonority. While the sonority profile of the right edge of the inflected form has been manipulated by previous studies (Table 1) to our knowledge no previous study has operationalised sonority dichotomously as flat versus falling. One possible explanation is that level sonority clusters, e.g. /pt/ and /kt/ involve greater articulatory effect as they require rapid movements of the articulators if both stops are articulated and released. In support of this, there was a significant association between the realisation of word final /t/ and /d/ in monomorphemic contexts, and the ability to produce the –ed affix, which for most of the stimuli resided within a word-final consonant cluster. This raises the possibility that a relatively mild and possibly sub-clinical speech or articulation difficulty may affect the realisation of complex clusters with a level sonority profile. This argument is likely to be controversial given that (a) morpheme omissions are often described as reflecting abstract phonological processes as opposed to speech or articulatory causes (Marshall & van der Lely, 2007) and (b) articulatory / phonological difficulties are not assumed to be a characteristics of the SLI phenotype. However, it has been observed that there are marginally higher rates of speech delay in children with SLI than exist in the general population, and moreover this co-morbidity is greatly increased in clinical contexts where comorbidity rates of up to 77% have been reported (Shriberg & Kwiatkowski, 1982; Shriberg, Tomblin, & McSweeney, 1999). Moreover, studies of past tense production in SLI do not generally include an in-depth phonological or articulatory screen, e.g. the Diagnostic Evaluation of Articulation and Phonology (DEAP; Dodd, Hua, Crosbie, Holm, & Ozanne, 2002). It is thus plausible that previous studies have recruited children with low-level phonological or articulatory difficulties, which may only manifest themselves when these children are required to produce clusters with level sonority, especially when they cross morpheme boundaries.

Another potential difficulty with level-sonority clusters is that the penultimate consonant, e.g. the /k/ in /kt/, is typically unreleased or weakly aspirated and therefore is comparatively difficult to detect. This might make it difficult for a child with a perceptual difficulty to recognise the word as an inflected form, and consequently build up the morphological paradigm. However, the role of auditory processing as an explanatory account of SLI has been undermined in recent years (Marshall & van der Lely, 2008)

While this study suggests that articulation may be an important and previously unrecognised factor, it cannot be the only factor. The morphological / syntactic aspects of past tense suffixation clearly have a role to play given that clusters are especially vulnerable in this context. One possibility, voiced by Marshall and van der Lely (2007), is that past tense morphemes involve the intersection of different kinds of complexity; phonological complexity (CC clusters), phonotactic complexity (illegal sequences), morphological complexity (affixation), and also syntactic complexity in the sense that the finiteness properties of the verb are dependent on its syntactic environment. To these multiple complexities we might also add the articulatory complexity of producing the cluster. This brings a new, and, according to one's viewpoint, extra-linguistic domain to the linguistic-representation focused account of Marshall and van der Lely.

#### *Limitations and future directions*

The findings of the study should be viewed in the context of a number of limitations. Firstly this was a repetition study as opposed to an elicitation study, and consequently, findings may have been influenced by perceptual abilities. In addition, the task may be easier than elicitation tests as the children are already given the correct model. However, some previous studies of past tense production in SLI have also presented the inflected form of the verb to the child, though not immediately preceding the child's response

(Marshall & van der Lely, 2006, 2007), and in this sense, methodological differences are minor. Furthermore, error rates in the current study are not greatly diminished compared to previous studies. For example, Marshall and van der Lely (2007) found an error rate of 21% for VC-D, though it should be acknowledged that these children are substantially older (mean age 12;03). Marchman et al. (1999) found zero suffixation rates of approximately 25% in an SLI group with ages ranging from 6;3 to 12;2. Consequently, there is little evidence that the task was made exceptionally easy due to the minimal demands of repetition. Finally, from a theoretical perspective, it has been argued that repetition is not altogether different from spontaneous production, as the surface form of the sentence rapidly decays, and therefore the participant must *reconstruct* the form of the sentence from representations in long-term memory (Potter & Lombardi, 1990).

Another potential limitation is the fact that, in contrast with previous studies (e.g. Oetting & Horohov, 1997), a baseline measure of word-final alveolar plosive production was obtained from connected speech, as opposed to being directly elicited. This has the advantage of being ecologically valid as it was based on naturalistic speech, but at the same time there was no control over the pre-alveolar context. Furthermore, scoring was relatively difficult as it was based on recordings, which deprived the rater of visual cues and sound fidelity is clearly not as good as when responses are scored live. A more bespoke test including monomorphemic items similar to the target words, e.g. *fact*, would have allowed one to investigate whether the data can be explained in terms of difficulties with particular clusters or sound combinations.

A further issue is that patterns of zero-affixation in the control group were not analysed as they were exceptionally low. It would have been interesting to see whether the observed effects of condition extended to this group. Marchman et al. (1999) found that profiles observed in children with SLI were also evident to a lesser degree in age-matched

peers. This suggests that the role of sonority observed in the SLI group may also play a role in typical children. A more highly-powered study could address this question.

Another issue is that, in controlling for sonority, other phonological factors, e.g. changes in place of articulation were allowed to vary. For example, while all of the level sonority items involved place changes in the final cluster, this was only the case for three items in the falling sonority condition; *served*, *saved*, *climbed*. Consequently rapid changes in place of articulation could underlie the effect of sonority. Sonority still has a role to play in the sense that sonority hierarchy is determined primarily by manner of articulation and voicing, and therefore to distinguish adjacent segments of equal sonority, manipulation of place is required. However, in this case it could be argued that the term “sonority” merely describes a more specific process; place change.

A final issue is that performance in the SLI group was far from homogenous with a group of five children with error rates greater than 20%. It could be the case that the omission profiles discussed are more characteristic of this subgroup, than the group as a whole. One approach to obtaining a more uniform group would be to include a past tense elicitation task as a screening measure in order to ensure relative homogeneity of past tense omission.

Future studies may build upon the current study by manipulating the sonority gradient in a more fine-grained manner than “level” and “falling”. In addition, it is recommended that more detailed and in-depth assessments of low-level speech / articulation difficulties be carried out in order to more accurately verify whether these difficulties can explain patterns of past tense omission. Finally, we need to be alert to the possibility of subgroups within SLI, who may find production of the regular past tense affix difficult for different reasons. For example, a more accurate differentiation between “standard” SLI, diagnosed using omnibus assessments such as the CELF and “Grammatical” SLI, identified



using tests which are focused on morphosyntactic difficulties, would enable one to verify whether low-level speech / articulation difficulties could act as a unifying explanation, or whether there exist subgroups where difficulties are of a specifically grammatical nature.

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#### *Declaration of interests*

I have no interests to declare

Appendix

Verb stimuli

	Stimuli		Monomorphemic equivalents of legal stimuli*
	Phonotactically legal	Phonotactically illegal	
Level sonority	kicked, packed, picked, dipped	baked, beeped, booked, cooked	edict, fact, strict, script
Falling sonority	poured, played, tossed, passed		sword, maid, frost, past
	knitted, posted, painted, planted, headed, started, patted, spotted, folded	served, saved, climbed, used	fetid, chorotid, candid, splendid

\* Sharing final three phonemes

Table 1

Studies showing an effect of stem-final phoneme on past production by children with SLI

Study	Division on sonority continuum (shown by   )
Marshall & van der Lely 2007	[a] > [e o] > [i u] >   [r] > [l] > [m n] > [z v ð] > [s f θ] > [b d g] > [p t k]
Eyer & Leonard, 1994; Oetting & Horohov, 1997; Johnson & Morris, 2007	[a] > [e o] > [i u] > [r] > [l] >   [m n] > [z v ð] > [s f θ] > [b d g] > [p t k]
Marchman et al. 1999 <sup>1</sup>	[a] > [e o] > [i u] > [r] > [l] > [m n] > [z v ð] > [s f θ] >   [b d g] > [p t k]

1. Marchman et al. explicitly analysed the category [+alveolar] thereby analysing \_\_\_/d/ and \_\_\_/t/ verbs as a separate category to \_\_\_/b/ \_\_\_/g/ \_\_\_/p/ and \_\_\_/k/ verbs. However their findings broadly reflect this division on the sonority hierarchy. A reanalysis of data in Table 5 shows much lower error rates for verbs above the plosive-versus-non-plosive cut-off than below (1.3 zero-marking errors per item versus 5.3 errors per item (n = 31) )

Table 2

Group Psychometrics (mean and s.d.)

	SLI n=17, 3 female	LM n=20, 10 female	Sig. differences (t-test)
WISC Non-verbal IQ	106 ( $\pm$ 14.4)	112.5 ( $\pm$ 11.5)	
MLUw	6.73 ( $\pm$ 1.0)	6.61 ( $\pm$ 1.2)	
TROG raw score (blocks)	4.6 ( $\pm$ 2.3)	8.1 ( $\pm$ 2.8)	p < 0.001**
RAPT raw score	20.9 ( $\pm$ 4.4)	23.4 ( $\pm$ 3.3)	
CELF WS raw score	9.29 ( $\pm$ 3.3)	12. ( $\pm$ 2.5)	p < 0.001**
BPVS raw score	57.2 ( $\pm$ 10.4)	62.9 ( $\pm$ 10.3)	
CNRep raw score	14.6 ( $\pm$ 6.8)	17.9 ( $\pm$ 4.2)	

Table 3

## Results of mixed effects logistic regression

Fixed effects					
	Coefficient	Odds ratio	SE	z	p
Legality					
(0 = illegal, 1 = legal)	-0.58	0.56	0.439	-1.32	0.187
Sonority profile					
(0 = falling, 1 = flat)	1.06	2.90	0.45	2.39	0.017*
Legality x Sonority interaction	-0.07	0.93	0.59	-0.12	0.906
Omission rates in monomorphemic contexts (covariate)	1.48	4.41	2.08	0.71	0.475
Random effects					
	Estimate		SE		
Legality (slope) <sup>a</sup>	0.00		0.40		
Sonority (slope) <sup>a</sup>	0.46		0.68		
Legality x Sonority Interaction (slope) <sup>a</sup>	0.00		0.87		
Item number (crossed)	0.89		0.46		

(a) With participant as intercept

Figure 1

Distribution of -ed omission rates by group

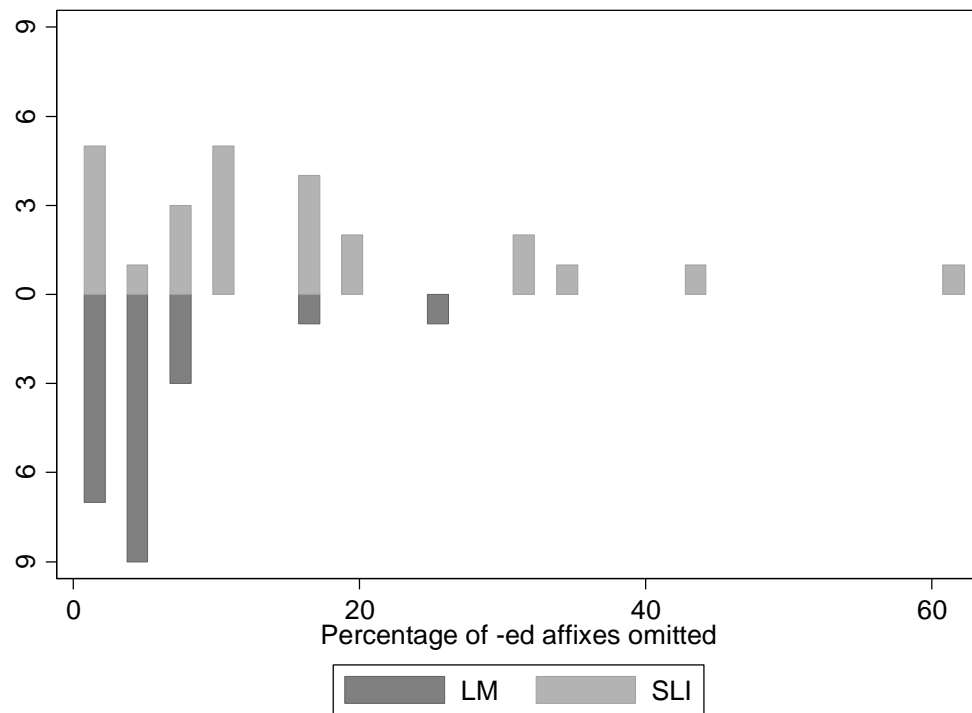
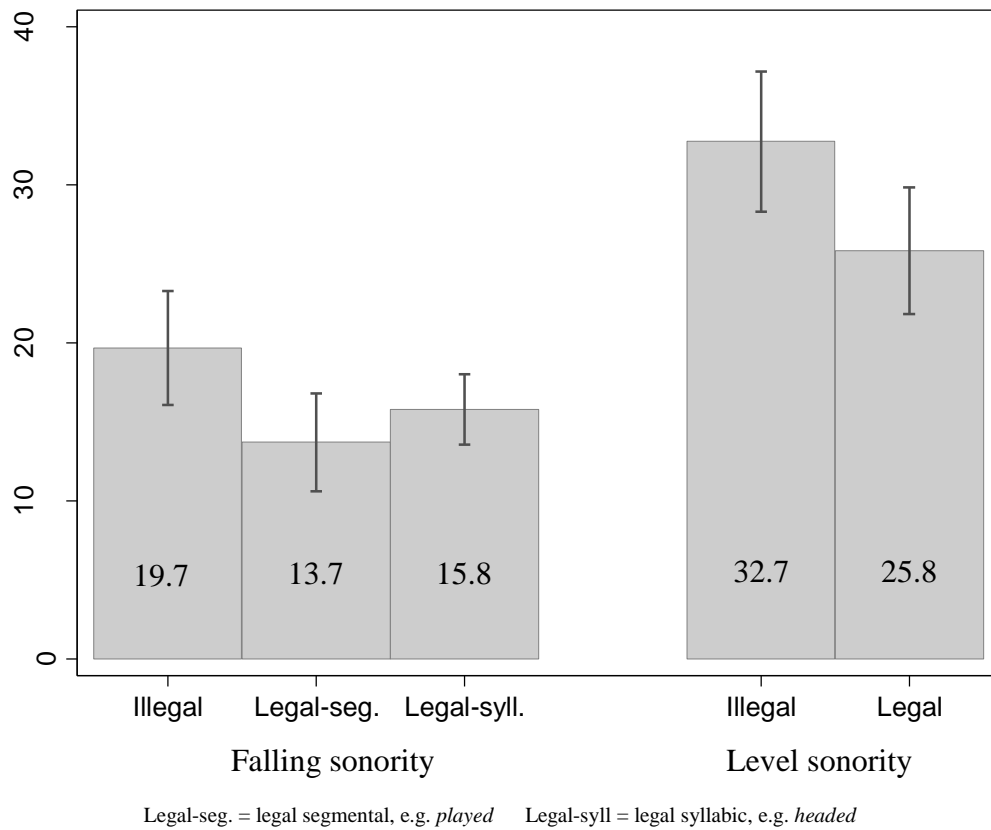


Figure 2

/t/ and /d/ omissions by children with SLI

Bars show standard error of the mean



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